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Experimental investigation of the effects of oxygenated fuels on exhaust emissions in a heavy duty diesel engine

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Abstract

Physical and chemical properties of biofuels vary among various feedstocks and their subsequent conversions to fuels. The biofuels contain various amounts of oxygen, and this has a significant influence on exhaust emission. This oxygen content has been considered in order to investigate its effect on diesel engine exhaust emissions. The experiments have been conducted with a heavy duty diesel engine and various oxygenated fuels. It is found that the amount of oxygen in the fuel has a high level of influence on its exhaust emissions, and this provides agreement with diesel emissions results such as PN reduction. By increasing the amount of oxygen in the blend (by adding more biofuel), the particulate number (PN) is reduced and NOx increases gradually. However, the variation of PN and NOx are not similar for waste cooking biodiesel (WCBD) and butanol blend, even though their oxygen content are the same in the blends. This is due to the source of the biofuel and their internal chemistry.

Keywords: Oxygenated fuel, Exhaust emissions, Particulate Number.

1. Introduction

The reduction of environmental pollutants from direct injection heavy-duty diesel engines is mandated by the Australian New South Wales (NSW) federal government and international organization regulations. The increases in prices of diesel fuel coupled with stringent emission regulations provide a mandate, prompting the researcher to investigate alternatives to conventional fuel [1, 2]. A key feature of biodiesel fuels, which makes them different from conventional fossil fuels, is the oxygen bound in the fuel. While there are always two oxygen atoms in one fatty acid methyl ester (FAME), the oxygen content in the biofuels depends on the fatty acid ester profile, specifically carbon chain length and unsaturation level [3]. Rahman et al.(2014) found that saturated short chain length FAMEs reduce NOx and PN concentration, but higher levels of fuel consumption and unsaturated FAMEs can lower PN, and produce higher NOx [4]. High-quality biodiesel should have low- temperature performance and oxidative stability. Therefore, it is found that oxygen in the fuel can enhance the combustion process as well as provide increased combustion efficiency and lower soot levels [1, 5]. Biodiesel contains a higher concentration of reactive oxidative species that may enhance combustion efficiency and reduce exhaust emissions [4].

Internal combustion engines, such as diesel engines, are used to convert chemical energy (contained in the fuel) into mechanical energy. In the conversion process, emissions are produced. Diesel engine emissions contain pollutants that have adverse health and environmental effects [6]. This mechanical energy and the exhaust emissions depend on fuel properties such as chemical composition, higher heating value (HHV), density, viscosity, and cetane number [7]. These physical properties depend on chemical composition and molecular structure of the biofuels. [8]. Nabi et al. [9] theoretically investigate the engine performance and exhaust emissions for different oxygenated fuels. Based on this literature, the authors have been motivated to investigate the effect of oxygen content on exhaust emissions, especially PN and NOx.

There are many oxygenated fuels has been used including WCBD and butanol to reduce diesel engine emissions can be found [1, 5, 10]. Recently, butanol has received importance as oxygenated fuels due to their advantage compare to methanol and ethanol. It has a higher cetane number, lower volatility and a higher flashpoint [10, 11]. For this reason, the current study has been conducted experimentally using WCBD/diesel and butanol/diesel blends to investigate exhaust emissions. It is found that PN and NOx change for both blends when compared with diesel fuel. The results show inconsistent emissions for various oxygenated blends.

2. Engine and fuel specification

The experiments were conducted at QUT in the Biofuel Engine Research Facilities (BERF) lab with a heavy duty common-rail four stoke six-cylinder turbocharged diesel engine. The engine has a capacity of 5.9 L and maximum torque of 820 Nm at 1500 rpm. Figure 1 shows the schematic of the experimental engine setup. Further detail of the engine configuration and emission

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measuring instruments can be found in Bodisco et al. [6]. The Engine was operated at consistent speed of 1500 rpm (maximum torque speed), and at two different loads - including 50% and 100%. Maximum load at any particular engine speed depends upon the type of fuel used, therefore for each fuel at the first maximum load was determined when the engine was at full throttle for a particular speed. The measured load is then considered as 100% load for that speed and fuel, and then other load conditions were determined, based upon measured 100% load.

Table 1: Fuel properties

Blends	O (wt%)	K.V@40°C (mm2/s)	Density(g/cc at 15° C)	HHV (MJ/kg)
Diesel [1]	0	2.81	0.8411	44
WCBD[5]	10.89	4.82	0.87	39.9
Bu [12]	21.6	1.13	0.9074	36.02
Bu_2	2	2.65	0.8381	43.26
Bu_4	4	2.49	0.8351	42.52
Bu_6	6	2.34	0.8321	41.78
WCBD_2	2	3.18	0.8464	43.24
WCBD_4	4	3.54	0.8517	42.49
WCBD_6	6	3.92	0.857	41.74

Before conducting the experimental studies, a careful fuel analysis needed to be carried out. It is broadly accepted that the fuel properties influence the fuel spray characteristics, fuel evaporation, the formation of fuel droplet size, distribution of fuel atoms, and, therefore the exhaust emissions. Petroleum diesel and two biofuels (WCBD and butanol) were used to prepare different blends. Three different blends were prepared for each biofuel maintaining the total oxygen content in the blends of 2%, 4% and 6% respectively. The important physicochemical properties of pure fuels were experimentally measured. Then, the used blends' properties were calculated based on pure fuel properties that is shown in the Table 1 [5, 8].

3. Emission measurements and data collection

Figure 1 shows a schematic of the engine exhaust emission measurements. Various instruments were used for exhaust emission measurements, such as DMS500, DustTrack (Model 8530), SABLE (CA-10) and CAI 600. The Combustion DMS500 is uniquely suited for a variety of diesel particulate filter applications. CAI 600 series analysers were used to measure raw exhaust gases such as CO, CO_2, NOx, and HC, and Sable and DustTrack used to measure diluted CO_2 gas and particulate mass respectively. Further detail of the engine exhaust emission measurements can be found in Rahman et al. [8].

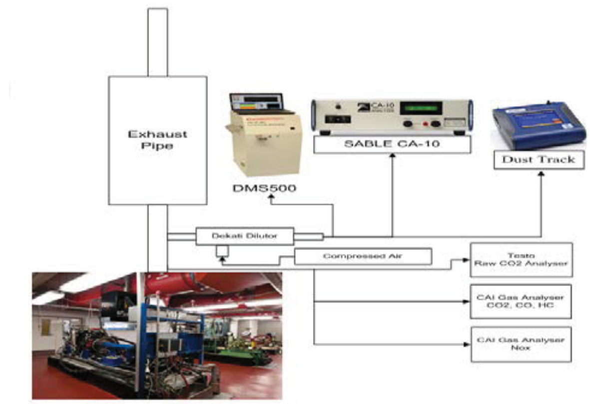

Figure 1: Experimental setup

4. Result and Discussion

The experiments were conducted with two different oxygenated biofuels - waste cooking biodiesel (WCBD) and butanol. The blends were prepared by adding a different amount of oxygenated fuel to the diesel. The blended fuel contained fixed amounts of oxygen, being 2%, 4% and 6% for each of the fuels.

4.1 Particulate number size distribution

The particulate number is the most complex emission parameter, and is receiving increased attention due to the associated possible adverse health effects [13]. Figures 2 and 3 present the PN size distribution at 50% and 100% load respectively. However, it was found from Figure 2 that the PN size distribution curve for WCBD blends was always under the diesel fuels curve. The pick point of the PN size distribution curve decreases with an increase in the oxygen amount - but not linearly. An exception was found for the 4% blend for both loads, that is, the range of particulate diameter was bigger when compared with other blends, and this can be found in Figures 2 and 3. The particulate diameter and number both reduced for 6% blends, compared with other fuels as shown in Figures 2 and 3.

Figures 4 and 5 present the PN distribution for butanol blends for 50% and 100% load respectively. The size distribution curve for butanol blends followed the same trend as for the WCBD blends. However, the particulate number was higher for butanol blends, when compared with WCBD blends for both loads. So, it could be said that PN size distribution not only depends on oxygen amounts, but it also depends on physiochemical properties of the fuel.

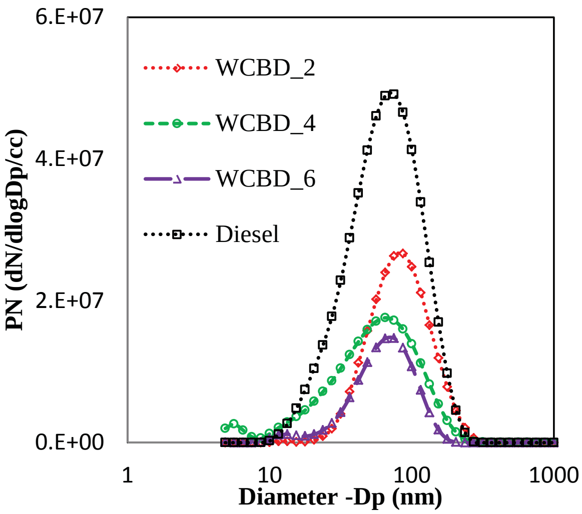

Figure 2: Variation of PN size distribution for oxygenated blends (WCBD) blends at 50% load.

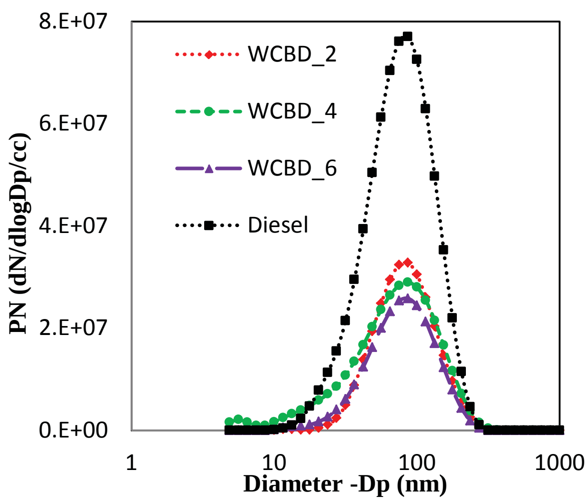

Figure 3: Variation of PN size distribution for oxygenated blends (WCBD) blends at 100% load.

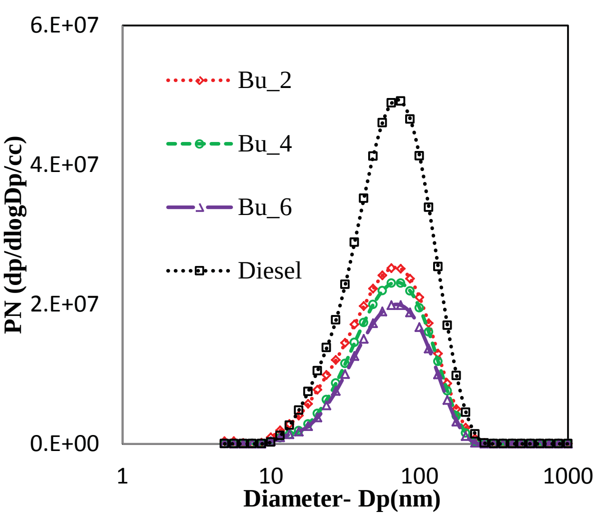

Figure 4: Variation of PN size distribution for oxygenated blends (butanol) blends at 50% load.

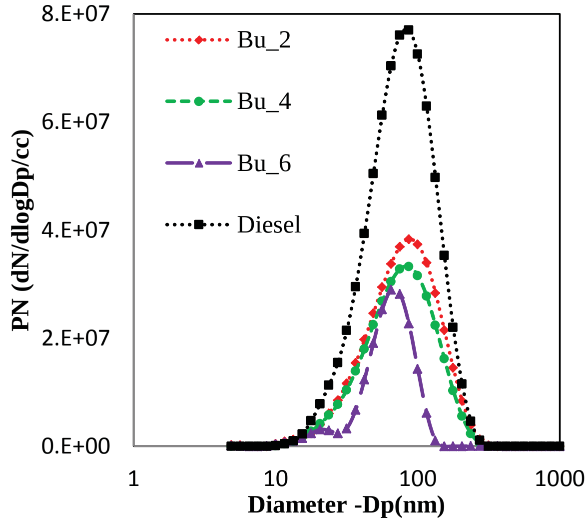

Figure 5: Variation of PN size distribution for oxygenated blends (butanol) blends at 100% load.

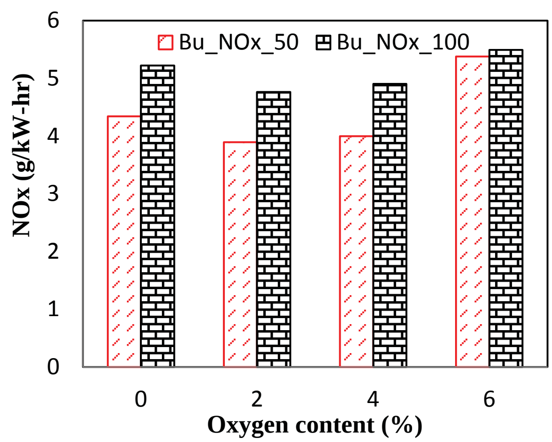

Figure 6: Variation of brake specific NOx emission for oxygenated blends (butanol) at two different loads including 50% and 100%.

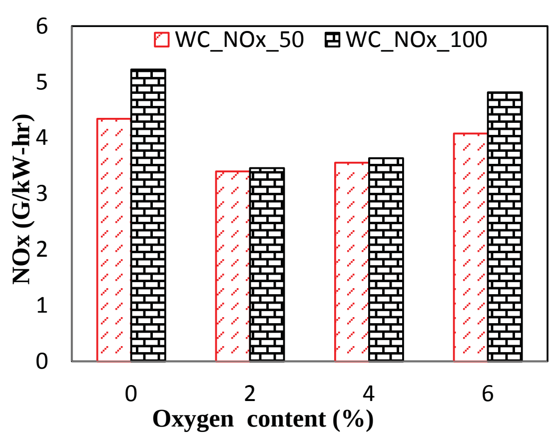

Figure 7: Variation of brake specific NOx emission for oxygenated blends (WCBD) at two different loads including 50% and 100%.

The specific NOx emissions were calculated against three different blends for both fuels and can be found in Figure 6 and 7. Noticeable variations in NOx emissions were observed among the three types of blends for two different types of oxygenated fuels. It was found that the specific NOx for all blends increased with increasing oxygen amounts except 0% oxygenated blends, as shown in Figure 6 and 7. The experiments were conduct at maximum torque conditions that could be reasons for the high specific NOx emissions for 0% oxygenated fuels. In additions, the further investigation could be helped to explain why specific NOx emission is the high for 0% blends. However, the rest of the results were similar to other publications, and can be found in Nabi et al. (2015) and Rahman et al. (2014) [1, 8]. It is also found that the rate of increase of NOx from 2% to 4% was low compared to the 4% to 6% blends for both fuels. The maximum increase in NOx was observed for 6% oxygenated blends, an observation common in the literature [14-16]. However, the oxygenated fuel came from a different feedstock. Therefore, the chemical and physical properties were different that influence combustion as well as combustion efficiency and exhaust emissions.

5. Conclusion

Experimental investigations on heavy duty engine exhaust emissions using three different oxygenated blends were prepared. The blends were prepared using diesel as a primary fuel, and WCBD and butanol were used as oxygenated fuels. It was found that the brake specific PN decreases with oxygen content in the blend, except for 4% oxygen blends for both types of oxygenated fuels. Conversely, the similar but opposite change was observed for variations of brake specific NOx emission. These results have primarily concluded that the increases of oxygen in the blend changes the chemical and physical properties that was influenced to change exhaust emissions.

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